Use of Vegetable Oils as Fuel in Combustion Engine: Engineering options

CIRAD *G.O.M.Vaïtilingom*

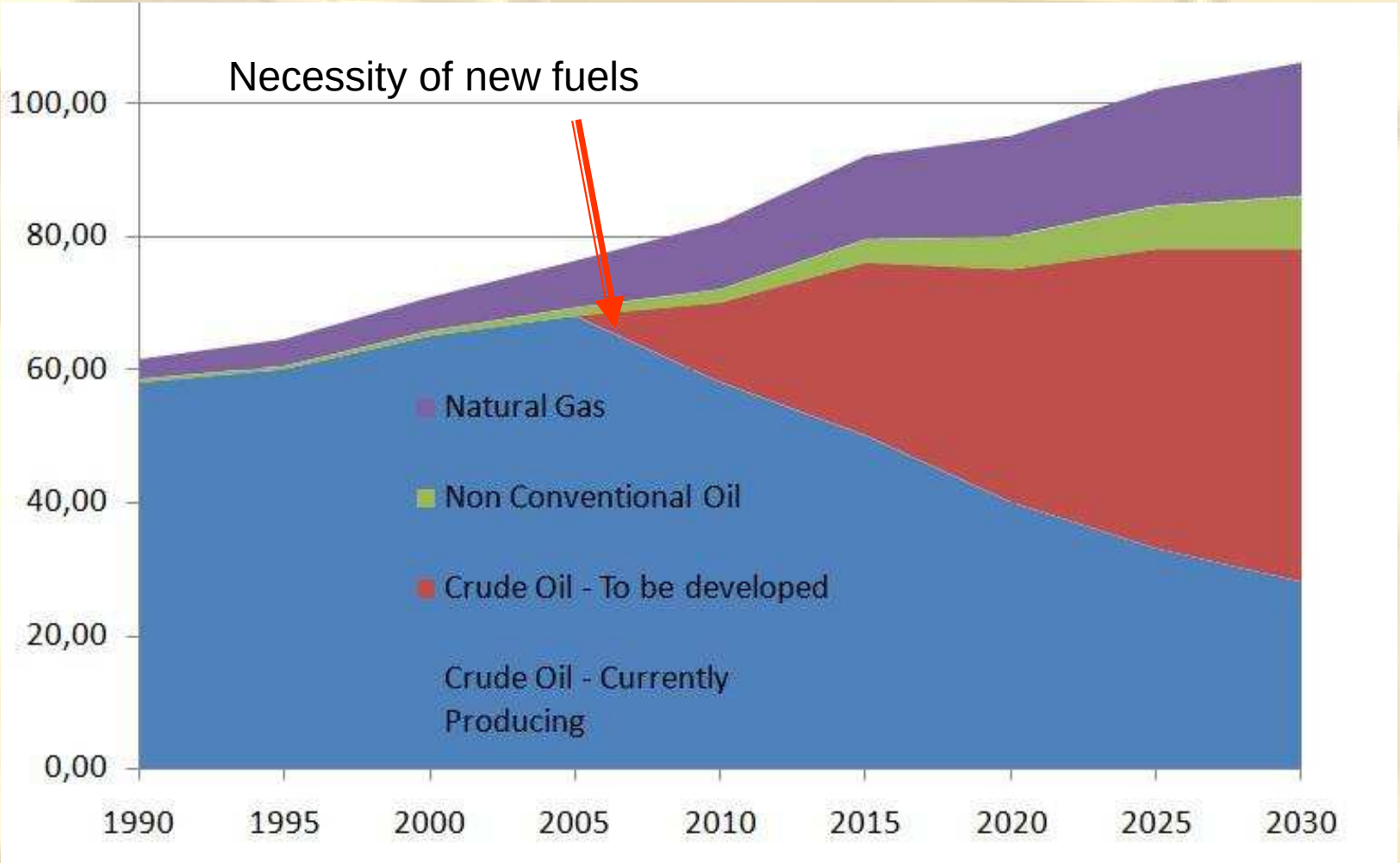
UFPA Universidade Federal do Pará *M.F.M. Nogueira*

COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future".
Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

SCOPE

- Introduction
- Vegetable oils as fuel for diesel engines
- Constraints to overcome
- Engineering options
- Example
- Engineering options for tomorrow

Introduction



Source: IEA 2008

COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

Introduction

NECESSITY OF NEW COMING FUELS AROUND 2010 !!

AT THE ENGINEERING LEVEL, CAR MANUFACTURERS ARE CONSIDERING 2030 (with 20-30 % non fossil fuel)

TO DAY TARGET IS ONLY CO_2 REDUCTION

COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

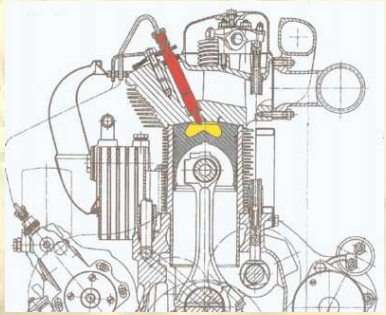
Introduction

The place of diesel and gasoline as unique liquid fuels for engines will decline soon.

Existing biofuels are:

Ethanol ⇨ spark ignition engines (Brazil has made it famous worldwide)

Vegetable oils pure and esterified ⇨ compression ignition engines



COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

History of vegetable oils as fuel

SINCE NEOLITHIC PERIOD : 9000 before J.C.

BUT: APARITION OF PETROL LAMPS IN 1853

History of vegetable oils as fuel

Rudolf DIESEL (1858 – 1913)

1900 : test of some vegetable oils in his engine

Natural Crude, pure, neat,…Vegetable oils

- **Characteristics close to diesel oil**

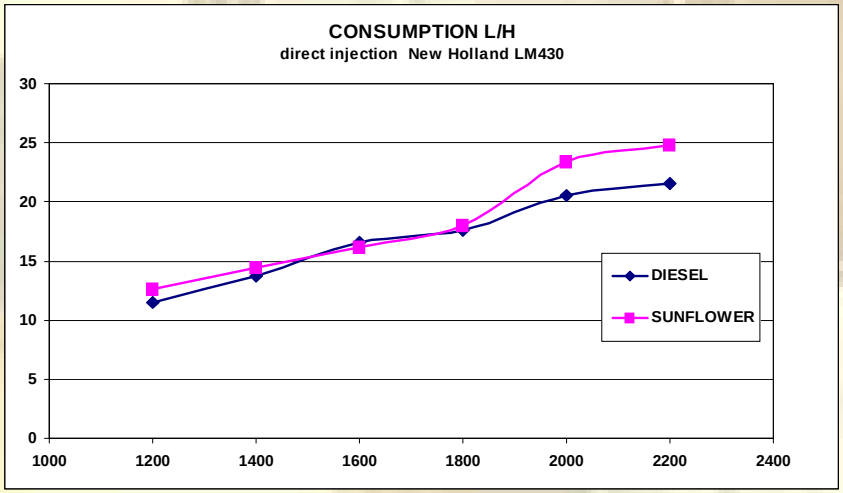
LCV coconut oil: 41 MJ/kg
LCV Diesel oil: 44 MJ/kg

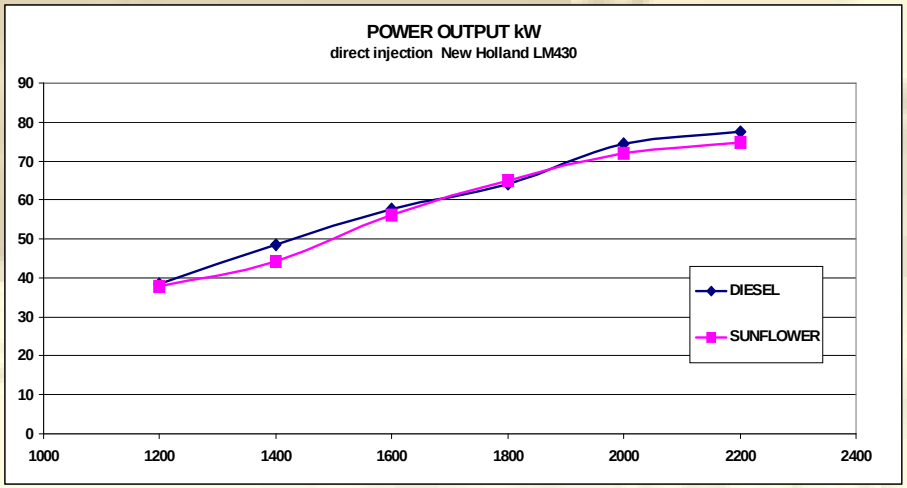
Density coconut oil: 0.92
Density Diesel oil: 0.83

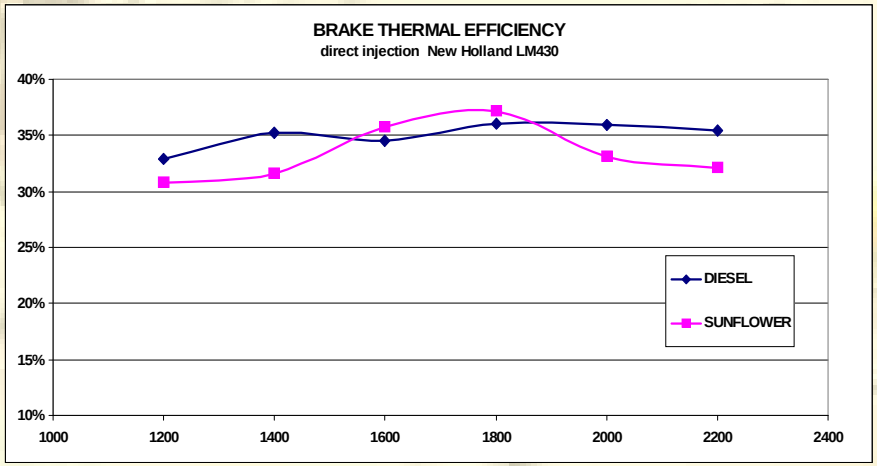
- **History:**

  - ***Mr. Diesel himself in 1900***
  - **World War II**
  - **Banned from research in the 50'**
  - **interest renewed at the end of 70'**
  - **But: last International Congress in 1982.**

Overall performance







Vegetable Oils as Fuel for Diesel Engines

Well known for their tendency for thermal or oxidative polymerisation… leading to carbon deposits.

Piston after 200 hrs. with diesel fuel at idle speed-no load

Piston after 21 hrs. with sunflower oil at idle speed-no load

WHY ?

COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

CONSEQUENCES (1)

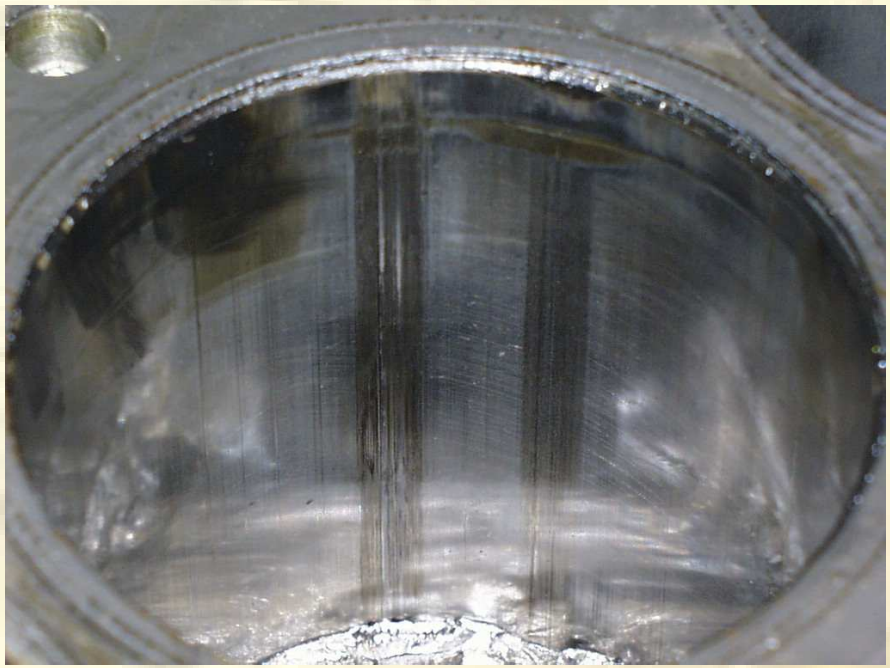
Long term operation eventually leads to engine breakdown.

CARBON DEPOSIT

Figure 10 - encrassement typique dû aux huiles végétales (piston de moteur à injection directe, 10 heures de ralenti à vide, huile de tournesol raffinée)

MECHANICAL DAMAGES

Injection pumps, rings, cylinder liner,…



COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

CONSEQUENCES (2)

CARBON DEPOSITS

valves,…

CONSEQUENCES (3)

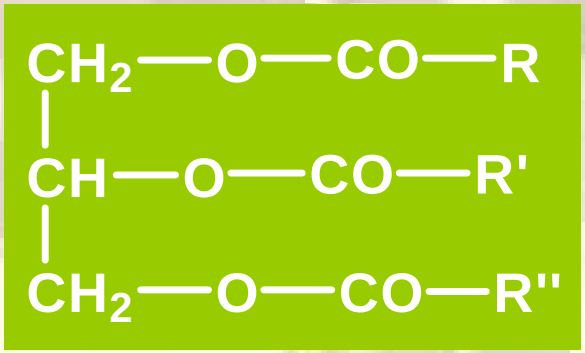
CARBON DEPOSITS

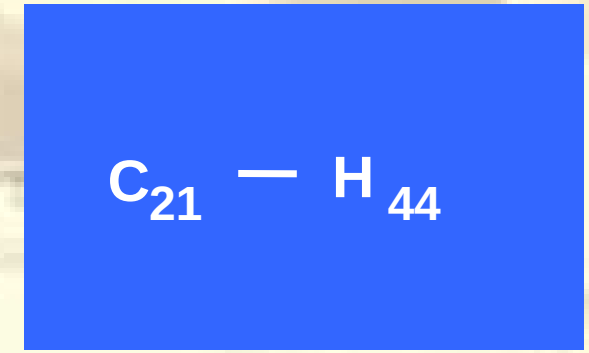
nozzle,

Nozzle tip after 21 hours running on pure refined sunflower oil

Idle speed – no load

VEGETABLE OILS / DIESEL FUEL





TRIGLYCERIDES > 90 %

HEATING VALUE : 35 – 41 (MJ/kg)

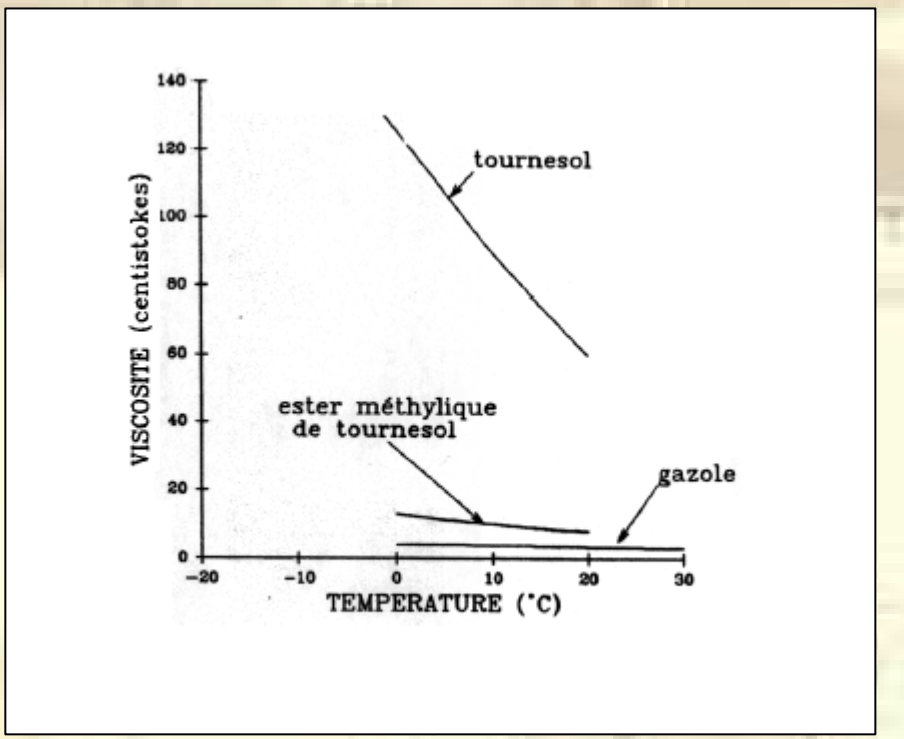
DENSITY : 0.91 – 0.94 (20°C).

HEATING VALUE : 43 – 44 (MJ/kg)

DENSITY : 0.83 (20°C).

CONSTRAINTS (1)

PHYSICAL CONSTRAINTS



DIESEL	:	- 35 ℃
RAPESEED	:	- 11 ℃
Coconut Oil	:	+ 23 ℃

VISCOSITY AT 40 °C : gazole < 5 Crude Palm Oil = 38 (mm_2/s)

SENSITIVITY to COLD COND.

Beginning of solidification

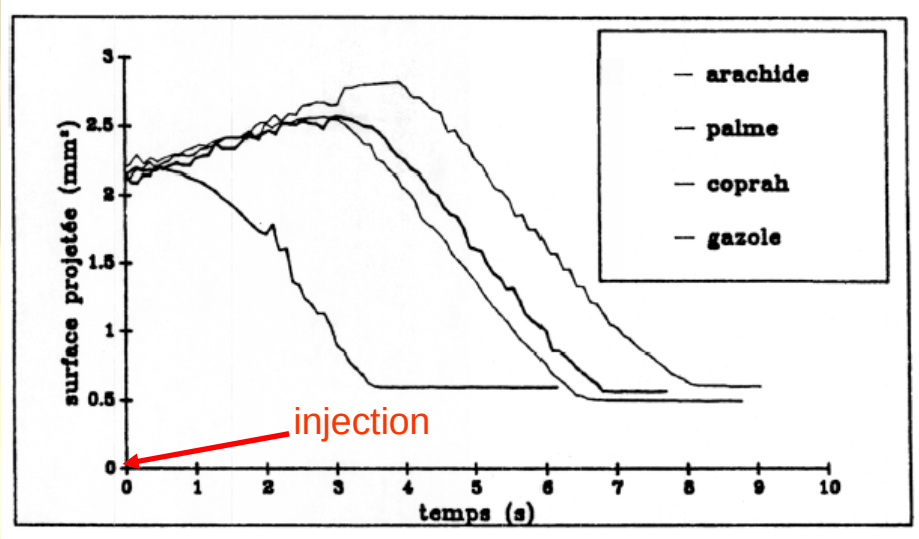
COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

Vegetable Oils as Fuel for Diesel Engines

Crude palm oil at 26℃ ; fractionating in two phase s

CONSTRAINTS (2)

CHEMICAL CONSTRAINTS



1. EVAPORATION OF DROPLETS at 630 °C

At 440 °C, only Diesel is totaly evaporated.

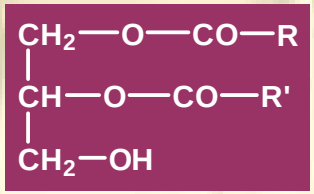
3. BAD PROPERTIES : siccativity
(sunflower : yes, rapeseed oil : no)

2. MINOR COMPONENTS :

GUMS, WAXES,…

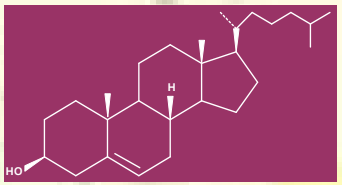
• partial Glycerides

(1 – 10 %)



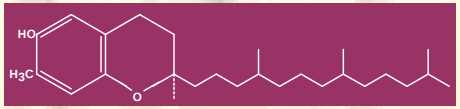
• Free Fatty Acids
(0.5 – 5 %)

• non-saponifiables, pigments… (0.5 – 2 %)

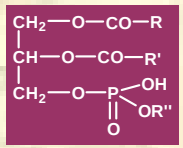


Sterols

tocopherols



• Phosphatides (0.1 – 1 %)



COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

Vegetable Oils as Fuel for Diesel Engines

Both physical and chemical constraints must be « overcome »

Making biodiesel (esterification) is a solution!

Reducing the viscosity is a necessity:

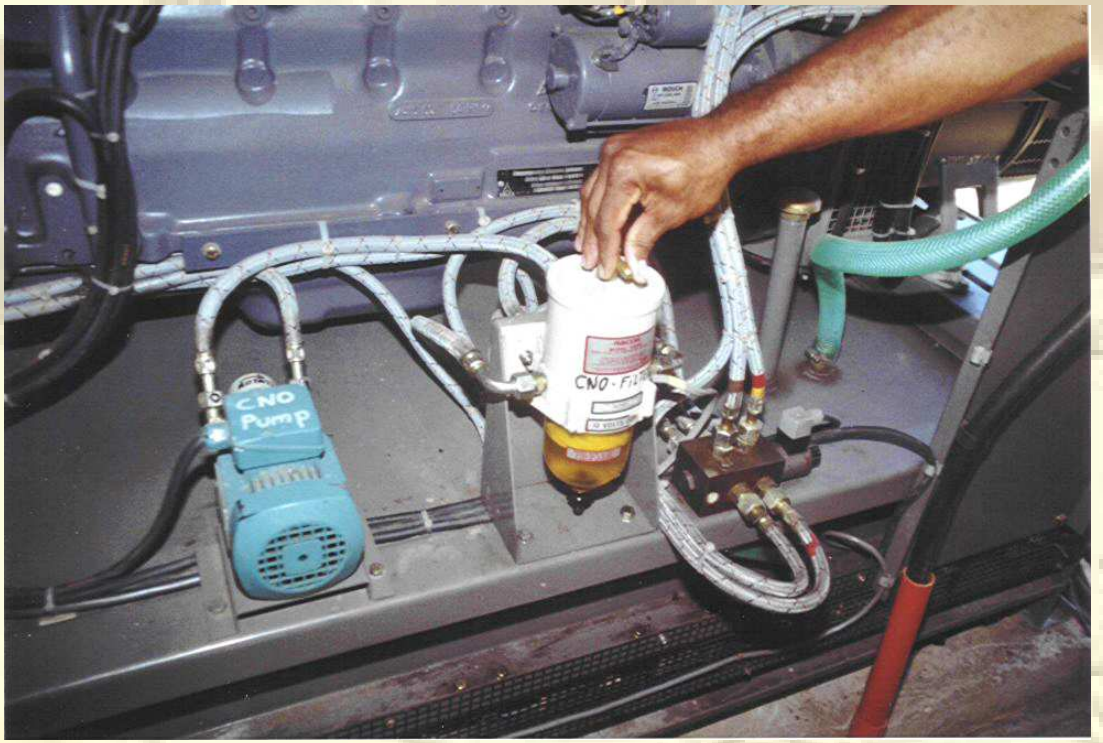
1. To keep a nominal flow rate in feeding line
2. To avoid mechanical damage on injection pumps (lack of lubrication due to high visco)
3. To keep an average droplet size and spray pattern respecting atomization conditions

Options:

1. **Over sizing tubes, lines and filters**
2. **Not necessary with inline pumps and Bosch rotary type VE**
3. **Increasing opening pressure (bars: 150 ➔ 200 IDI; 220 ➔ 300 DI)**

COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

Vegetable Oils as Fuel for Diesel Engines



If vegetable oil temperature can be under 100℃ => larger surface of filtration

If vegetable oil can become solid => heated filters and feeding lines

Vegetable Oils as Fuel for Diesel Engines

AC electrical heaters under and inside a coconut oil tank

Vegetable Oils as Fuel for Diesel Engines

Heating and filtration unit – coconut oil

2004 GENSET. 300KVA
Power Station of ENERCAL (Utility)
New Caledonia

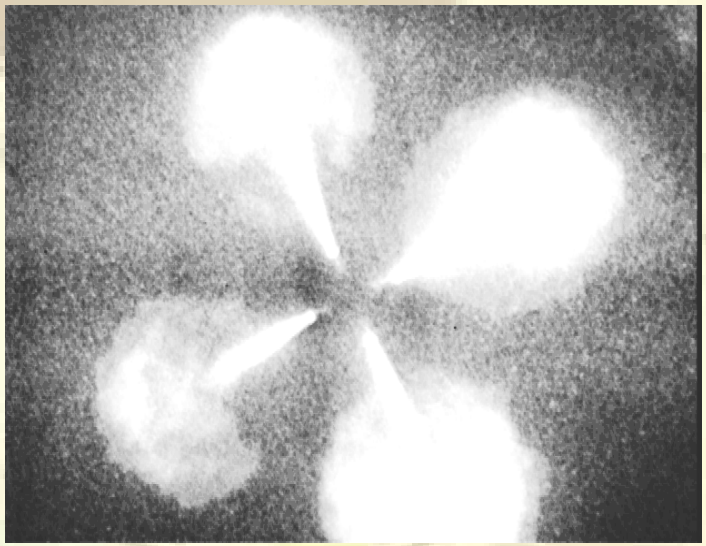
COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

Vegetable Oils as Fuel for Diesel Engines

Heating and filtration unit – coconut oil

2004 GENSET. 300KVA
Power Station of ENERCAL (Utility)
New Caledonia

Vegetable Oils as Fuel for Diesel Engines

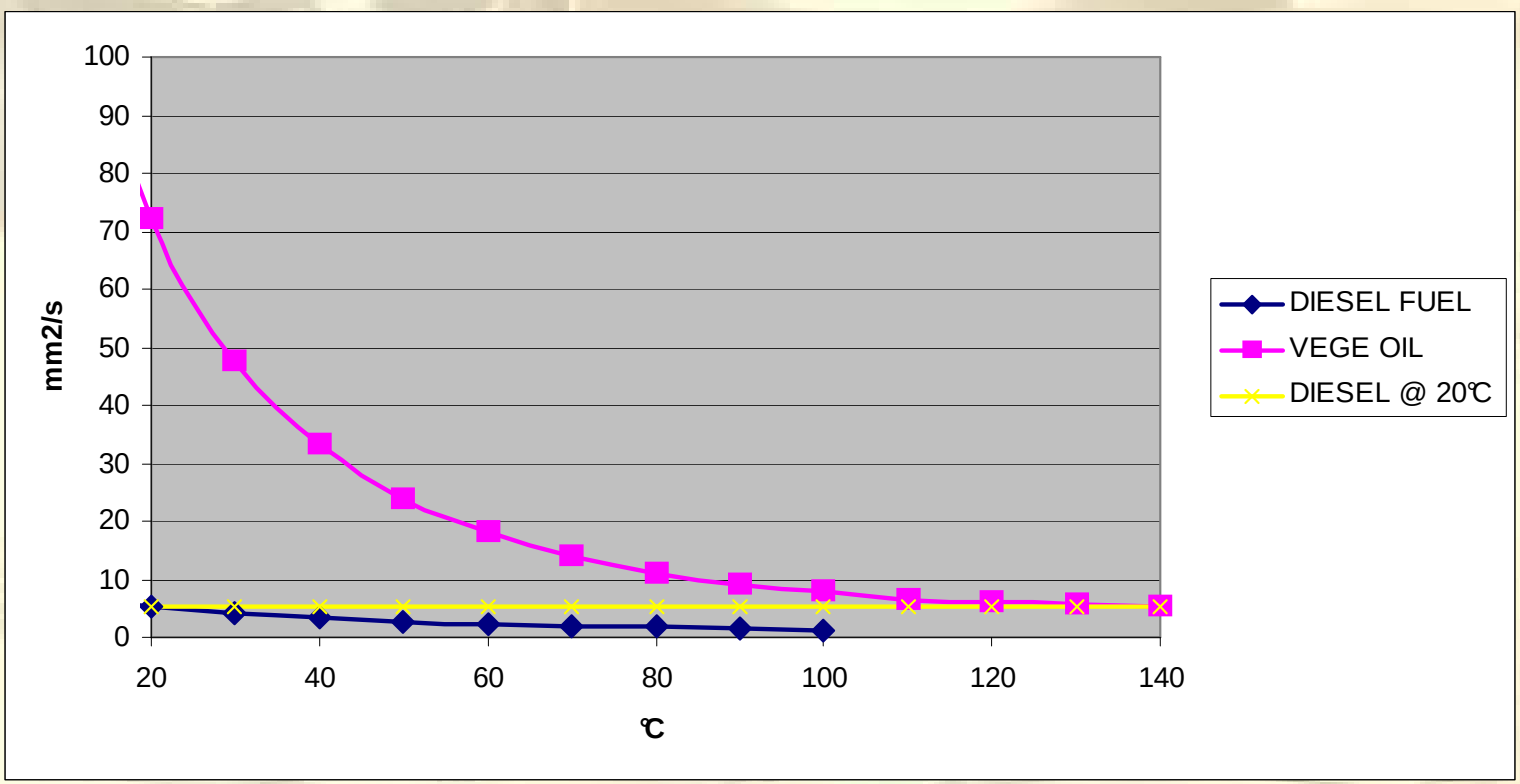


IDI: opening pressure 200 bars ; DI opening pressure 300 bars

COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future".
Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

How to reduce viscosity ?

- HEATING UP THE VEG OIL

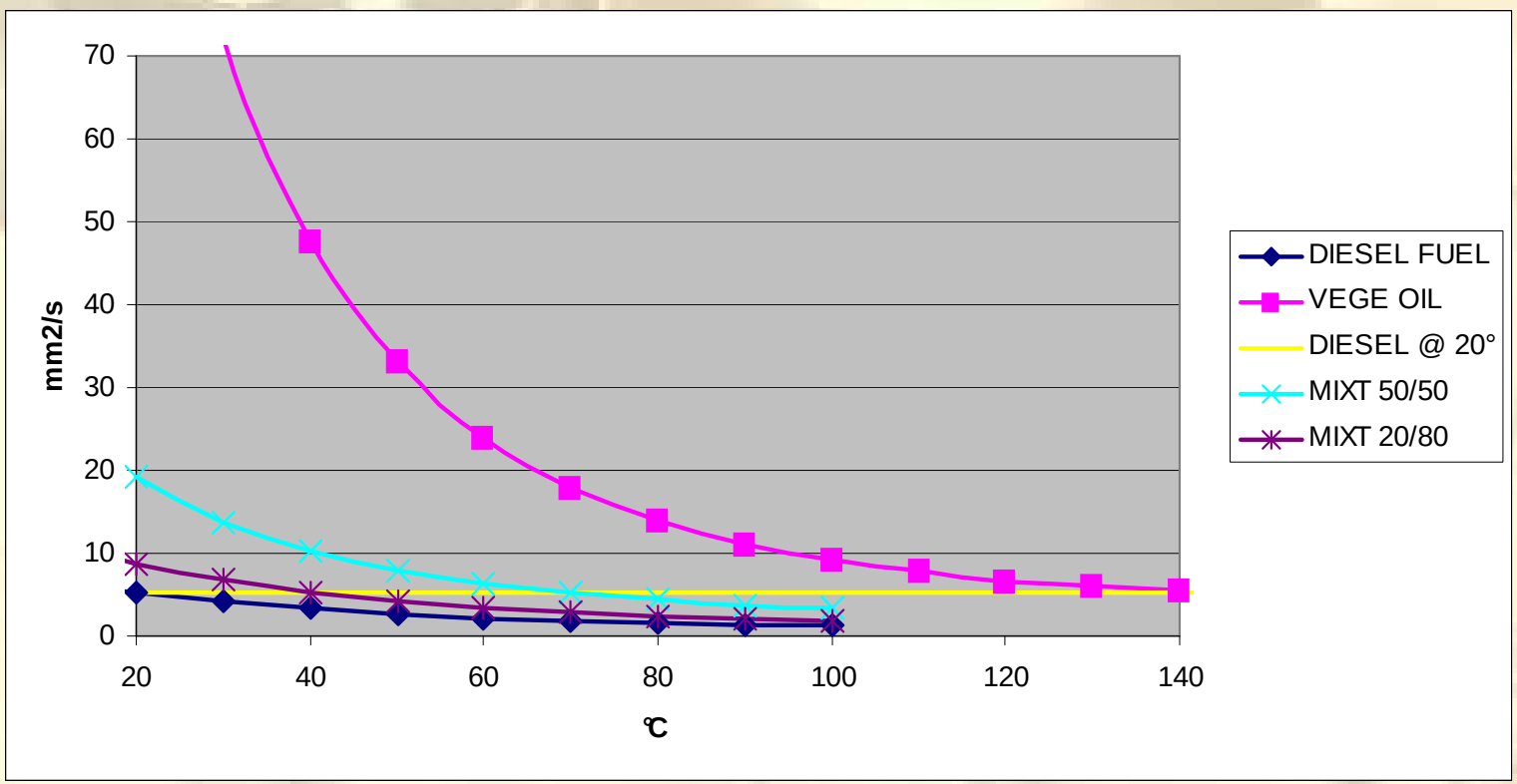


GOOD! BUT TEMP. Must be > 120℃

COLD STARTING ??

How to reduce viscosity ?

MIXING WITH A LESS VISCOUS FUEL (diesel fuel, Biodiesel, kero,…)



OVER 20%, heating up the mixture is a necessity

COLD STARTING ????

Means to reduce viscosity are a necessity for technical reasons.

BUT: Unless the « additive » is chemically modifying the vegetable oil, there is no lowering in chemical constraints.

Vegetable oils do not distillate completely. Some part is not evaporated and polymerize on combustion chamber walls. Then pyrolysis is occurring leading to carbon deposit formation.

If the average temperature of the chamber is above 500℃ then remaining veg oil is sublimating: combustion is complete and there is no carbon deposit.

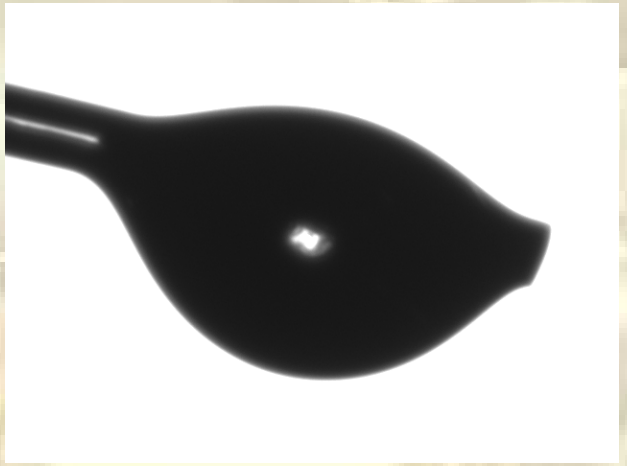
COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

Vegetable Oils as Fuel for Diesel Engines

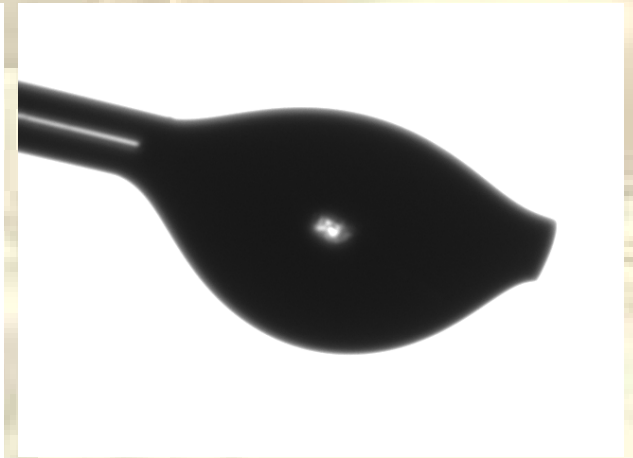
Movies: evaporation of a droplet of mixture diesel fuel/refined rapeseed oil

- 1: pure diesel fuel @ 350℃
- 2: mixture 50/50 @ 350℃
- 3: mixture 50/50 @ 500℃

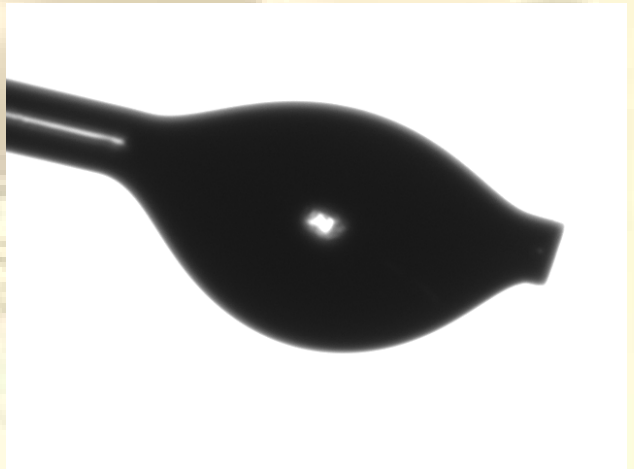
Vegetable Oils as Fuel for Diesel Engines



DIESEL FUEL 350℃



MIXT 50/50 350℃



MIXT 50/50 5 00℃

COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

Vegetable Oils as Fuel for Diesel Engines

In conclusion:

1. Atomization conditions must be respected,

2. Average temperature of combustion chamber must be > 500℃

Engineering Options

Vegetable oils:

1. In standard Diesel engines by either:

- **adapting the "fuel" and making *Biodiesel* (esterification with methanol or ethanol).**
- **using pure vegetable oils or mixtures under internal thermal conditions allowing their complete combustion (2- tank systems)**
- **using IDI engines (Indirect injection system)**

2. In specifically designed engines modified to burn vegetable oils at any percentage

COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

Engineering Options

Vegetable oils:

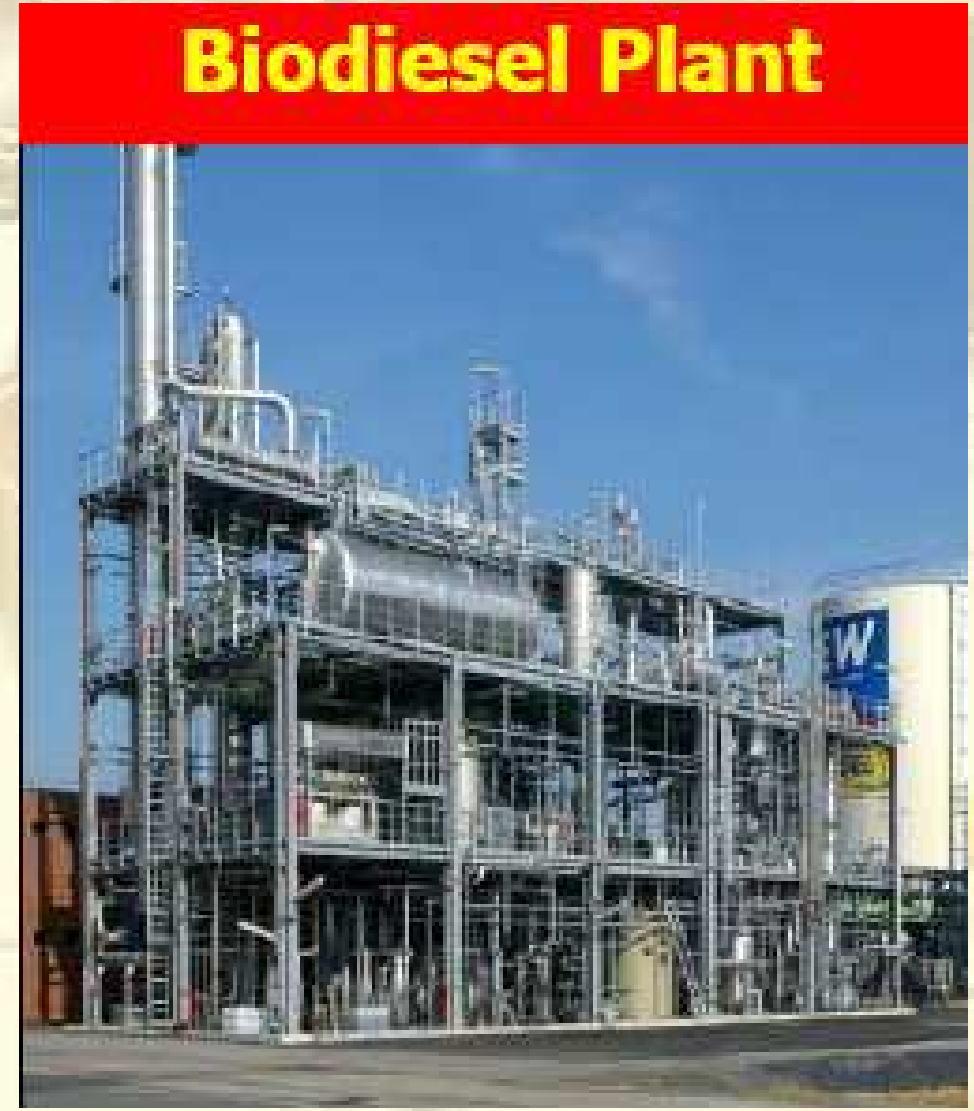
1. In standard Diesel engines by either:

adapting the "fuel" and making *Biodiesel* (esterification with methanol or ethanol).

- **Viscosity is close to diesel fuel one ➔ atomization**
- **Distillation of Biodiesel is total (almost) (chemical structure is modified)**
-

COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future".
Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

METHYL ESTER OF VEGETABLE OIL



Engineering Options

Vegetable oils:

1. In standard Diesel engines by either:

- adapting the "fuel" and making *Biodiesel* (esterification with methanol or ethanol).
- **using pure vegetable oils or mixtures under internal thermal conditions allowing their complete combustion using a 2- tanks system**
- using IDI engines (Indirect injection system)

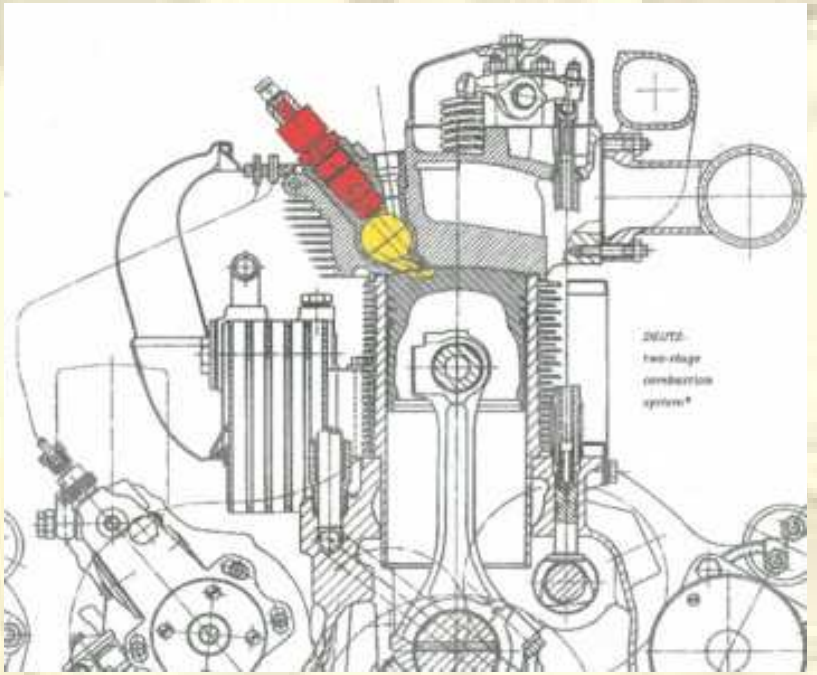
2. In specifically designed engines modified to burn vegetable oils at any percentage

COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future".
Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

HOW IS IT POSSIBLE TO OBTAIN THE REQUESTED TEMPERATURE IN ORDER TO USE VEGETABLE OIL ?

INDIRECT INJECTION : YES

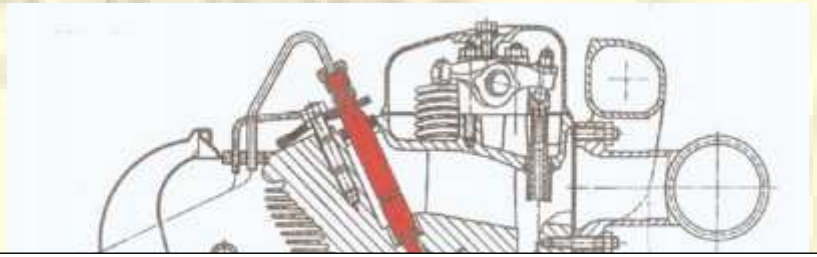
As soon as engine at idle: Tmoy > 500 ℃

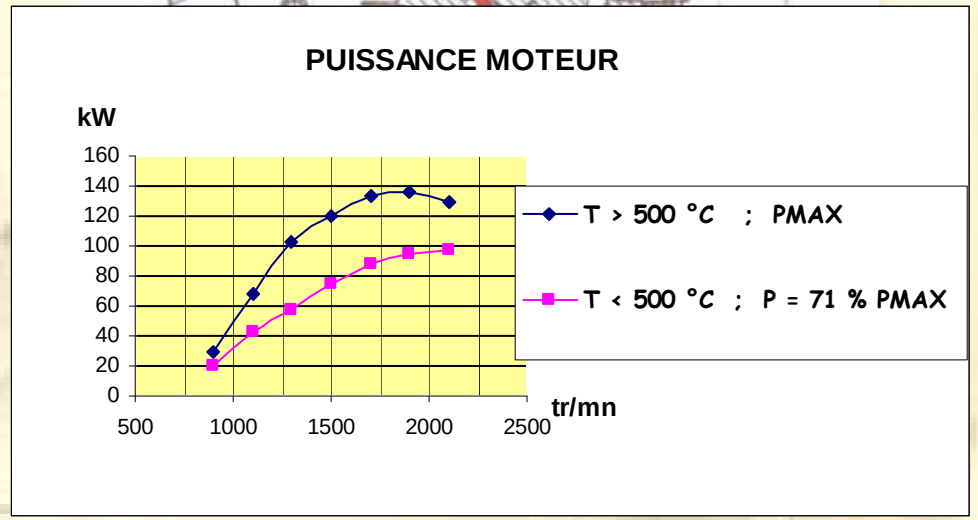


DIRECT INJECTION : YES, IF

Power output > 70 % of MAX.

If not NO !





COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

SYSTEM OF DOUBLE CIRCUIT or 2 TANKS SYSTEM

KIT for 2-TANKS SYSTEM

Renault dci 270 Ch (2006)

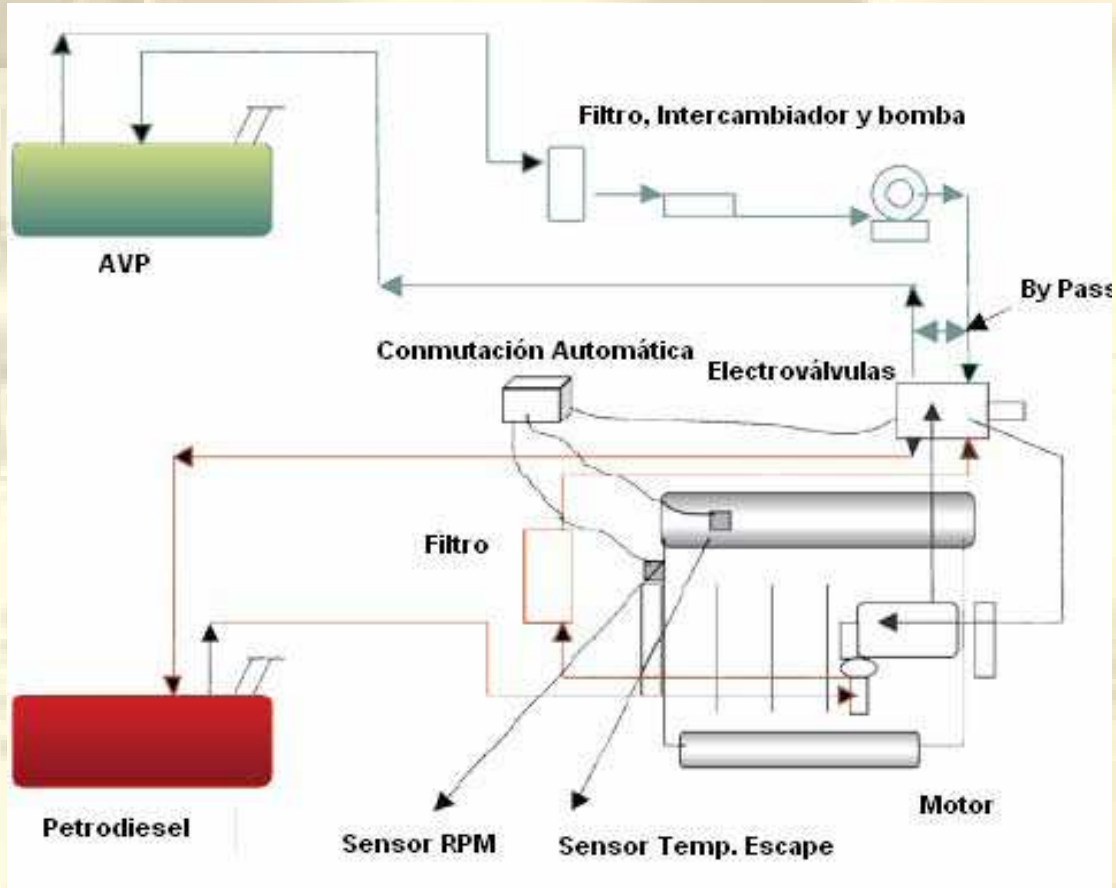
Common Rail injection

SUNFLOWER OIL

DIESEL DIRECT INJECTION **SUNFLOWER OIL**

SYSTEM OF DOUBLE CIRCUIT

Renault dci 270 Ch (2006)



BUT RUNNING ON SUNFLOWER OIL only WHEN LOAD > 65 %

COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future".
Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

IVORY COAST

SYSTEM OF DOUBLE CIRCUIT or 2 TANKS SYSTEM

Genset 320 kVA – crude Palm Oil (2006)

BUT RUNNING ON PALM OIL only WHEN LOAD > 50 % => 160 kVA

EXAMPLE OF MIXTURES OF COCONUT OIL

in STANDARD DIRECT INJECTION ENGINES

BUT RUNNING ON CNO AT LOAD > 50 % => > 200 kVA

Cummins genset , 400 KVA, 10-20 % CNO in DIESEL FUEL

Savai'i EPC Power station, Samoa (2005)

COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future".
Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

EXAMPLE OF MIXTURES OF COCONUT OIL in STANDARD DIRECT INJECTION ENGINES

BUT RUNNING ON 15 to 20 % CNO only WHEN LOAD > 50 %

Figure 21: UNELCO Generators in Port Vila running on coconut oil fuel blend *(Source: UNELCO)*

4MW MAN 9L32/40 generators on blends fuel/coconut oil
UNELCO Port Vila – 2006
Coconut oil is mixed or not to diesel fuel according to the load. (similar to a 2 tank-system)

Engineering Options

Vegetable oils:

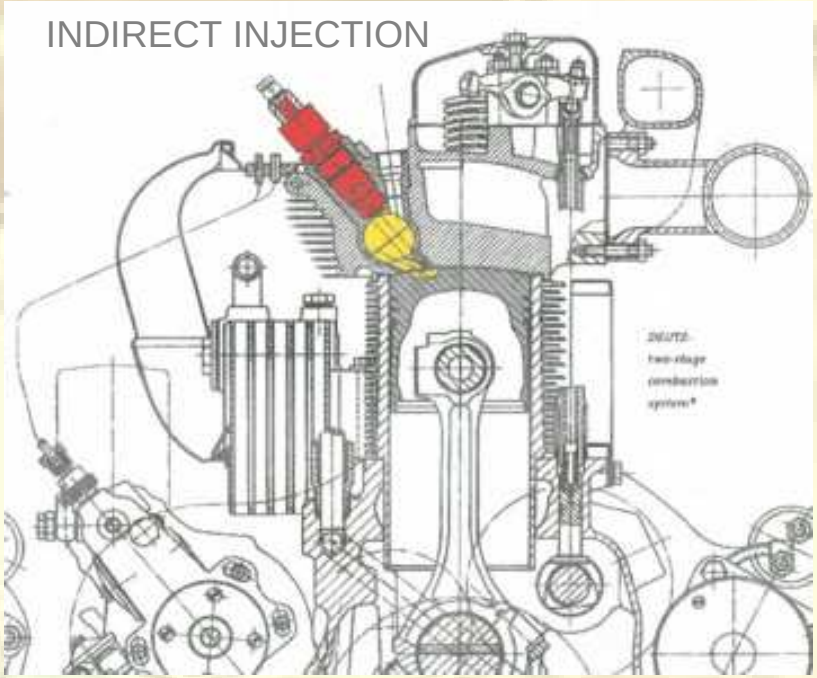
1. In standard Diesel engines by either:

- adapting the "fuel" and making *Biodiesel* (esterification with methanol or ethanol).
- using pure vegetable oils or mixtures under internal thermal conditions allowing their complete combustion (2- tank systems)
- **using IDI engines (Indirect injection system)**

2. In specifically designed engines modified to burn vegetable oils at any percentage

COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

INDIRECT INJECTION (IDI)



No modifications, only adaptation

Up to 100 % vegetable oil.

Heat exchanger and/or mixture with diesel fuel to reduce vegetable oil viscosity

& Some settings

DIESEL INDIRECT INJECTION

EXAMPLE

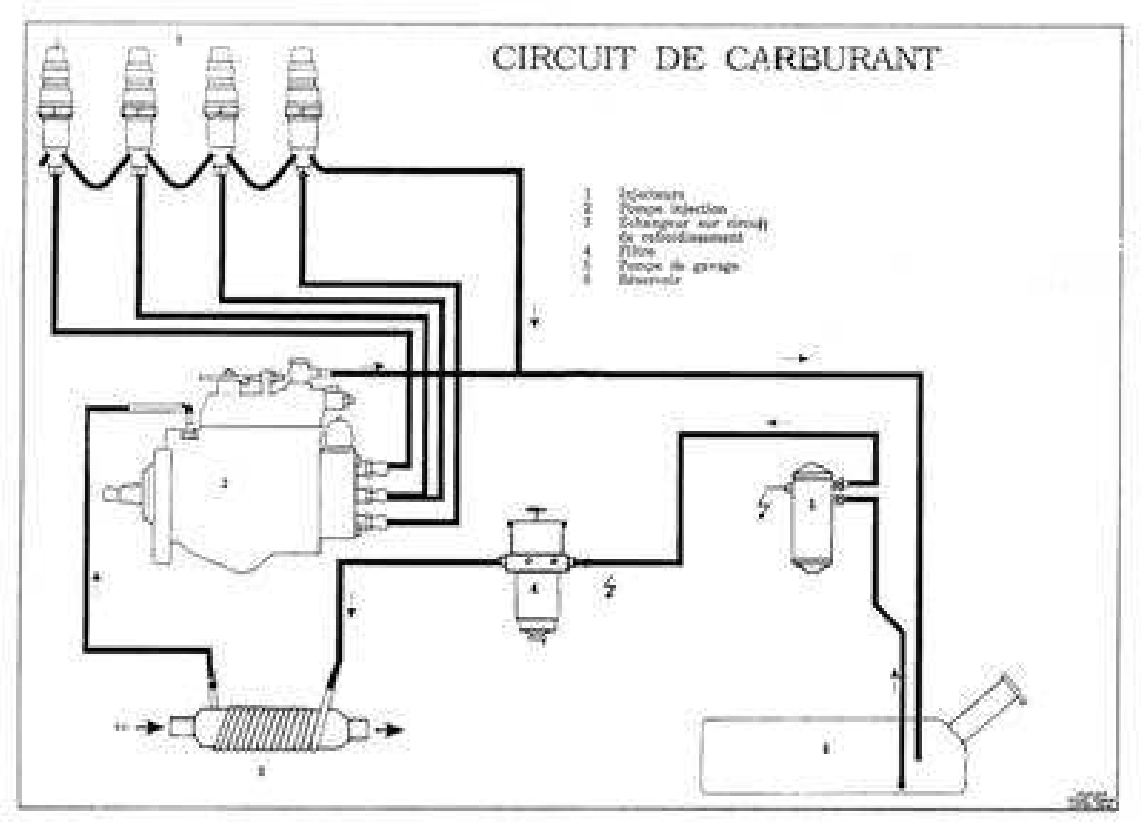
400 000 km with rapeseed oil (CIRAD)

SETTINGS

- **injectors opening pressures: 200 bars**

Photo: Rabaul Hotel car

IDI coconut oil powered car in PNG. (Atul Raturi, 2006)



COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future".
Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

CRUDE COCONUT OIL AS FUEL

IDI ADAPTED ENGINES

RURAL ELECTRIFICATION:

Fiji: Vanuabalavu 80 kVA* (2000) & Welagi 45 kVA (2001)

Coconut Oil as fuel (10 nuts = 1 litre equivalent Diesel Fuel)

** First place in the World to produce grid electricity with its own vegetable oil (April 2000).*

Engineering Options

Vegetable oils:

1. In standard Diesel engines by either:

- adapting the "fuel" and making *Biodiesel* (esterification with methanol or ethanol).
- using pure vegetable oils or mixtures under internal thermal conditions allowing their complete combustion (2- tank systems)
- using IDI engines (Indirect injection system)

2. In specifically designed engines modified to burn vegetable oils at any percentage

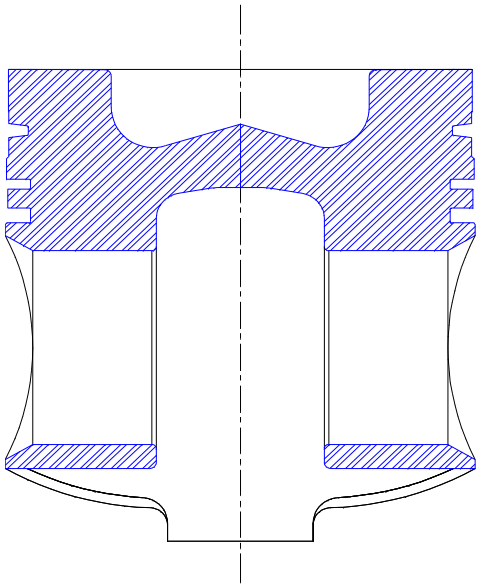
COBEM2009*, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009

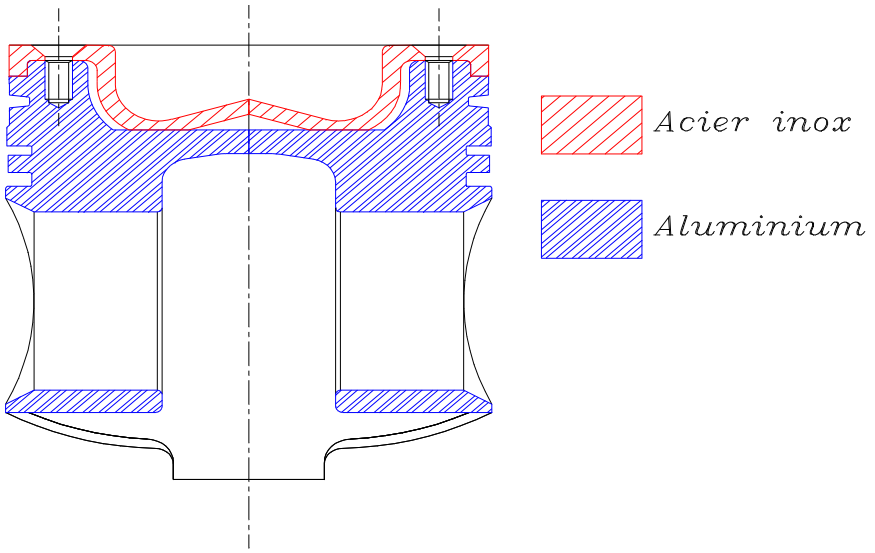
Vegetable Oils as Fuel for Diesel Engines

Modification of pistons

Example of combustion chamber

Example of combustion chamber





Vegetable Oils as Fuel for Diesel Engines

DIESEL DIRECT INJECTION

In specifically designed engines

In specifically designed engines

Tractor Biocombustible Yumz D-65 M, Sunflower or soja

UBPC Victoria 2, Camagüey – CUBA (2003)

Vegetable Oils as Fuel for Diesel Engines

Tractor Yumz (Camagüey - Cuba)

Spare Piston

modified Piston

COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

Vegetable Oils as Fuel for Diesel Engines

Example of a 60 kVA genset

UFPA, Belém, Faculdade de Engenharia Mecânica

1st phase: 2 tanks system

Diesel fuel substitution in vol. ☞ 60%

2nd phase: use of additives to speed up the combustion kinetics

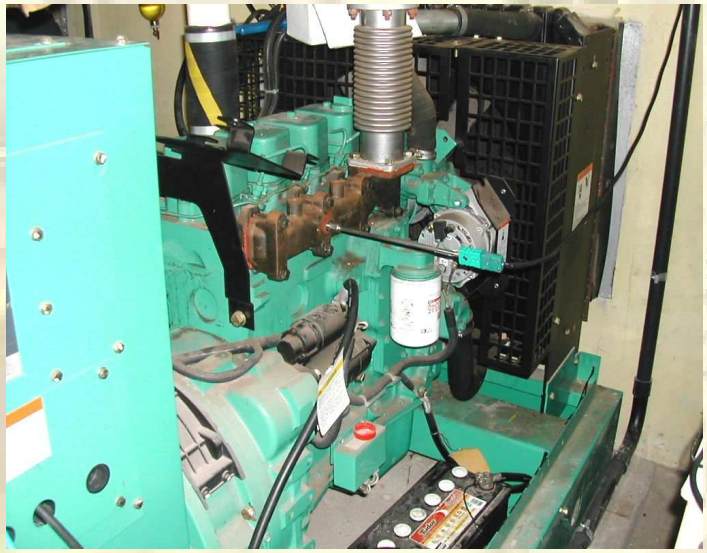
3rd phase: modification of pistons

Diesel fuel substitution ☞ 100%

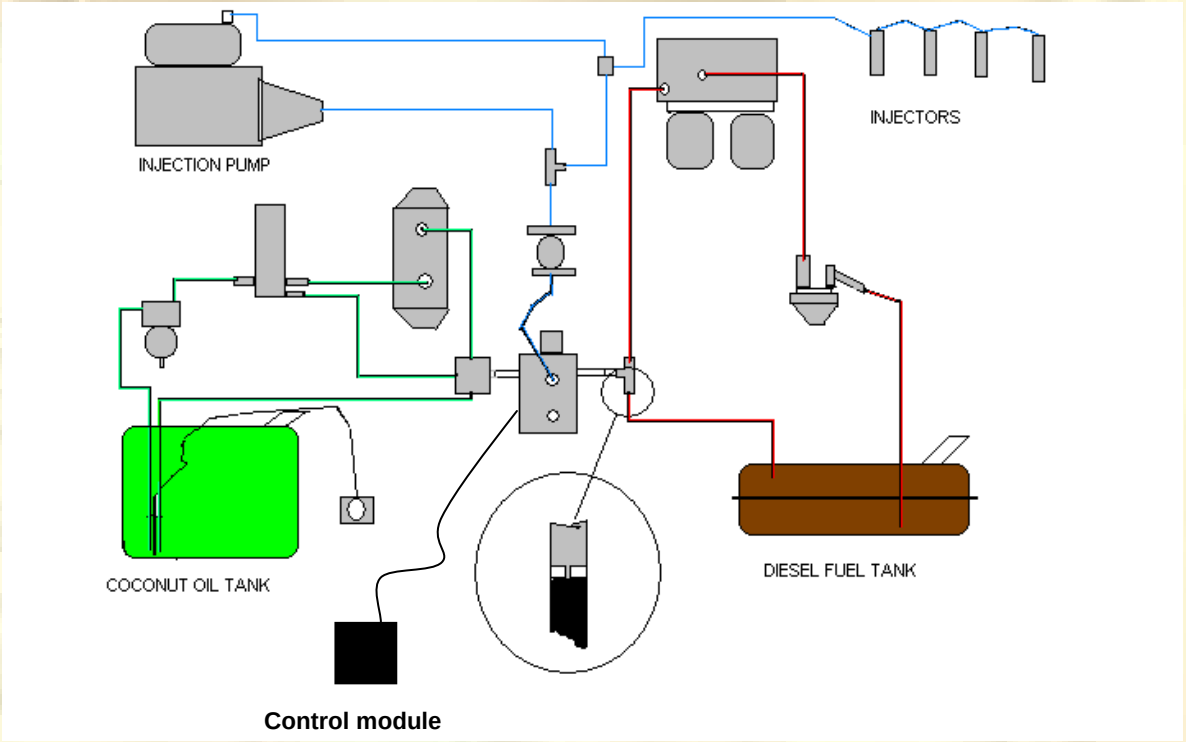
COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

1st phase

SYSTEM OF DOUBLE CIRCUIT or 2 TANK SYSTEM



Genset Cummins 60 kVA
(UFPA,Brazil, 2009)

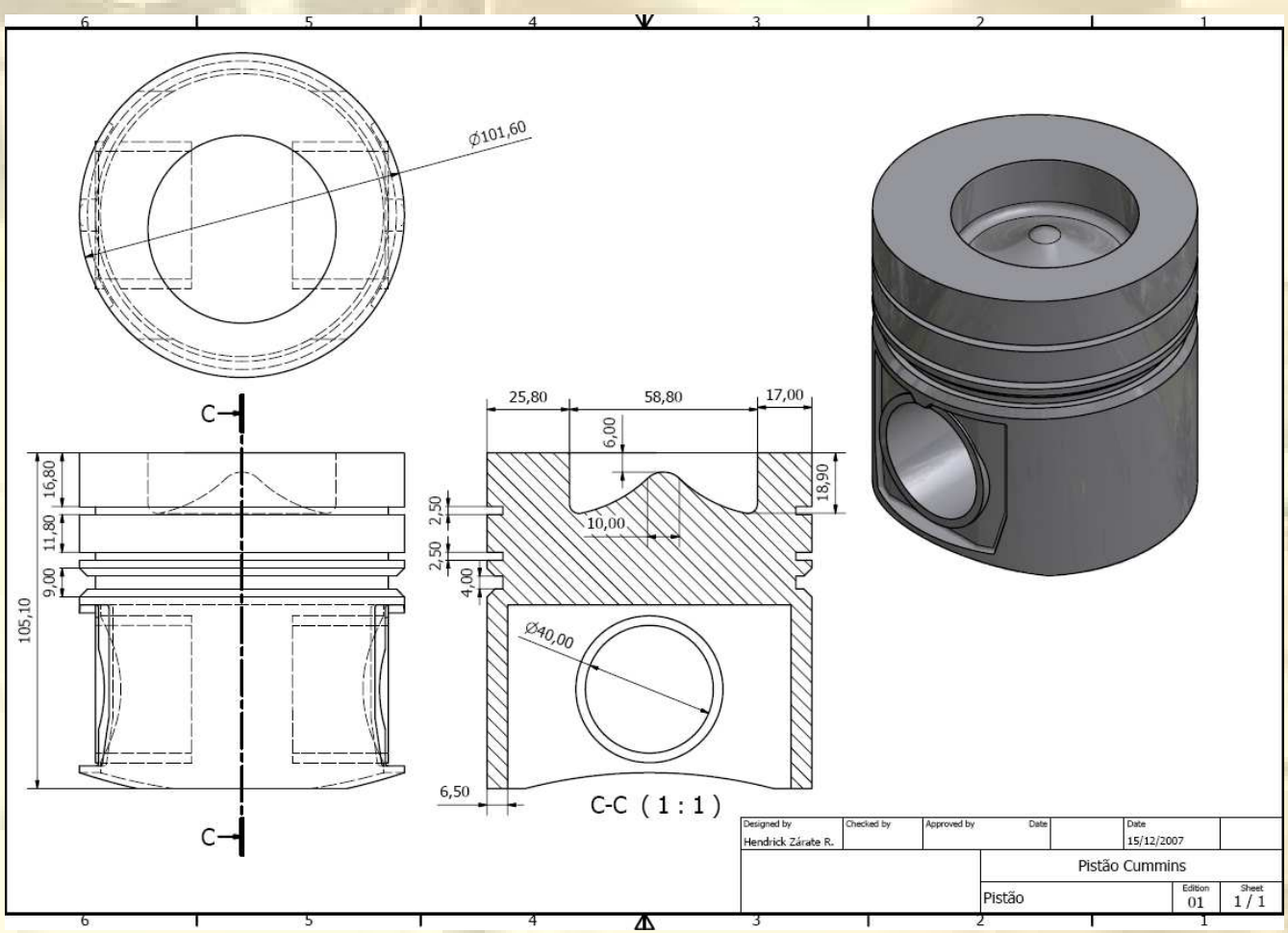


Control module

Running on Diesel Fuel from 0 to 30 kVA (load < 50 %)

Running on pure vege Oil from 30 to 60 kVA (load > 50 %)

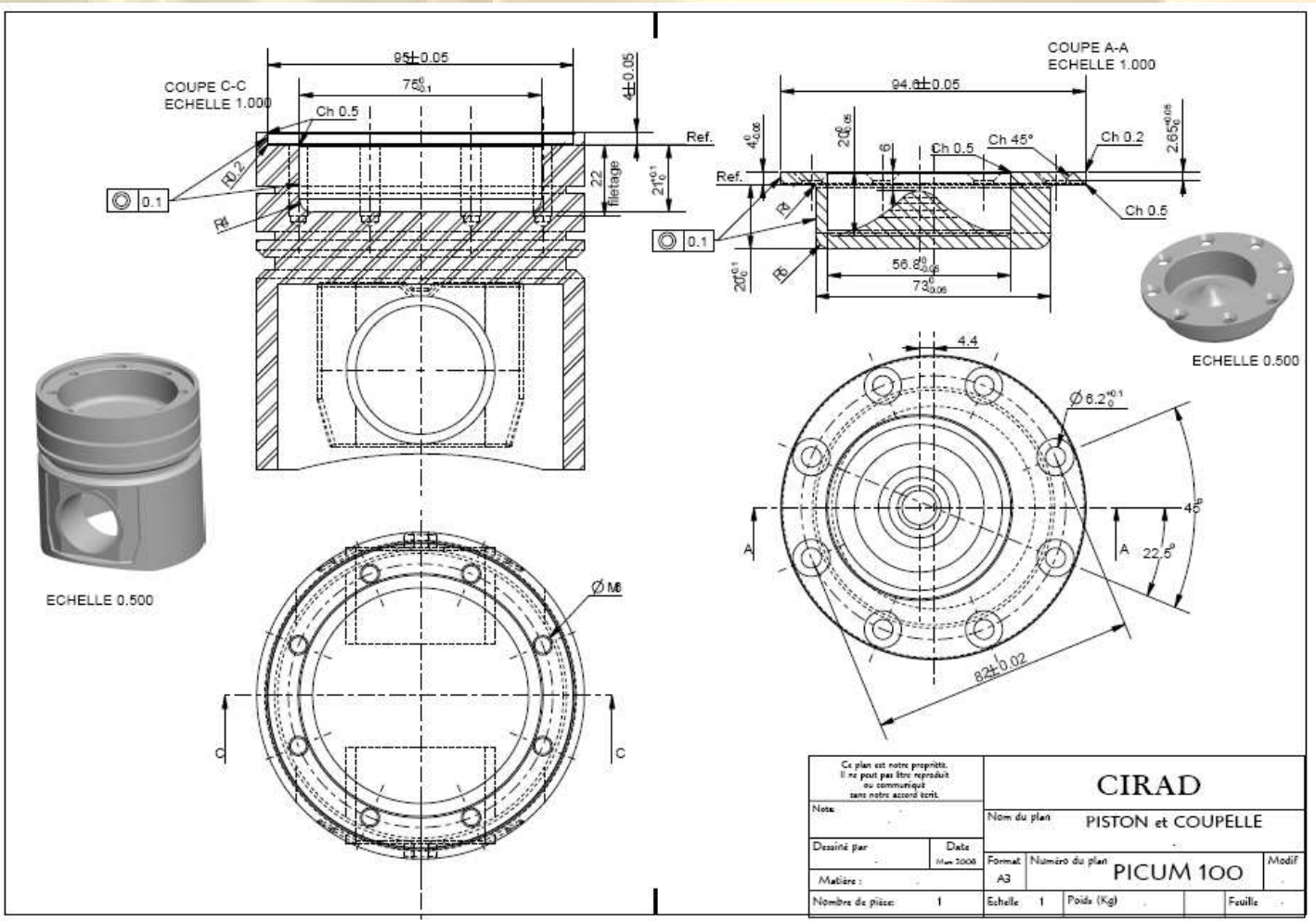
3rd phase



COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

3rd phase

Example of a modified combustion chamber



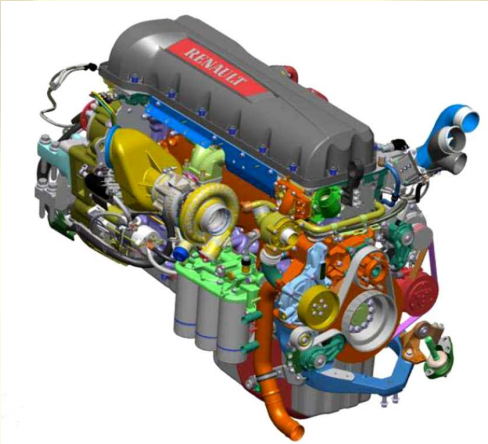
COBEM2009, 20th International Congress of Mechanical Engineering – *"Engineering for the future". Symposium: Combustion and Environmental Engineering. Gramado-RS, Brazil, November 15-20, 2009*

Engineering Options For tomorrow ?

Investigation to undertake with HCCI (Homogeneous Charge Compression Ignition) **engines + EGR** (Exhaust Gas Recirculation).

Example : **NADI** (**N**arrow **A**ngle **D**irect **I**njection). Homogeneous combustion at low load and conventional diesel combustion at high load.

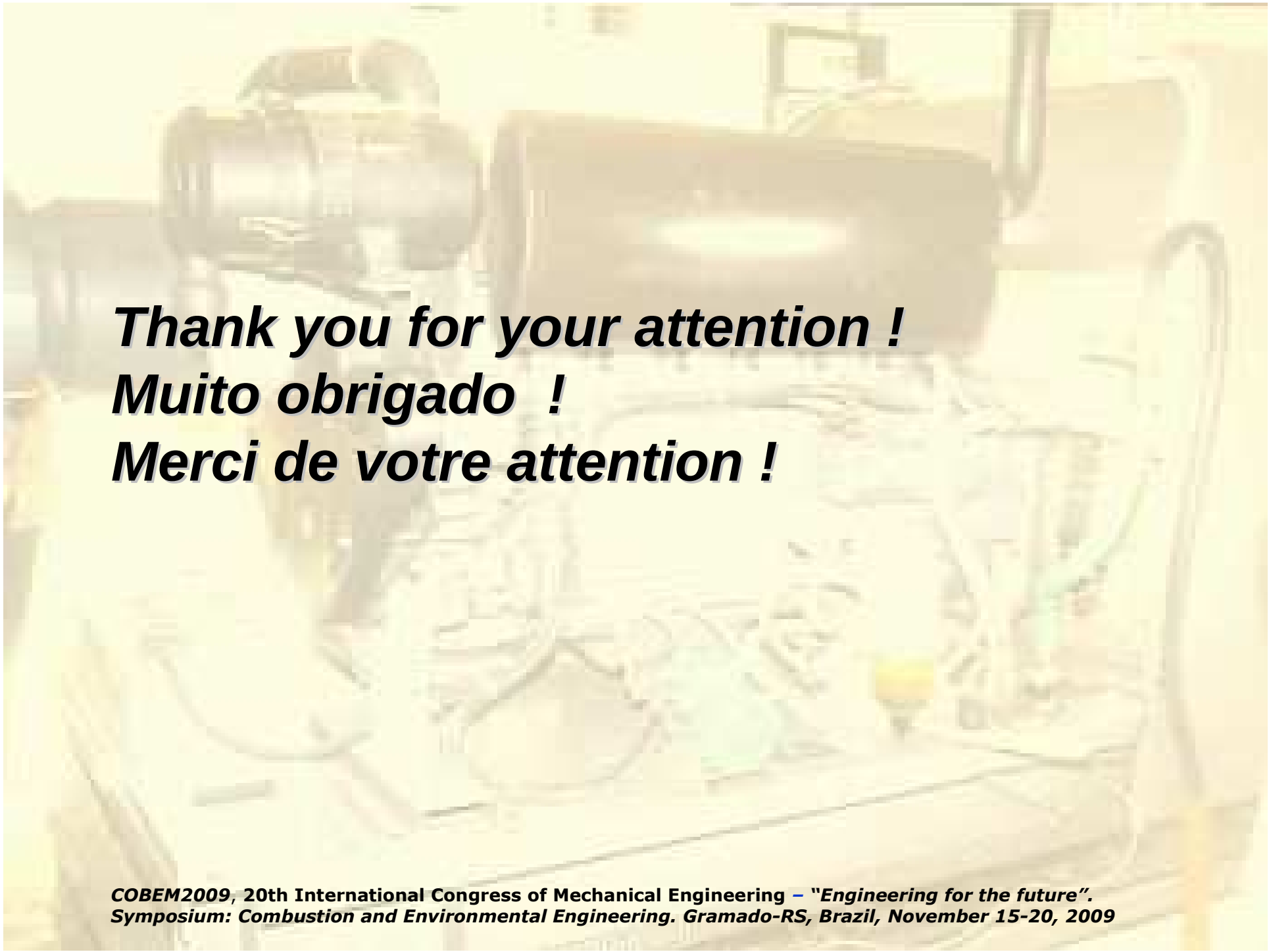
- High injection pressure (1600 b.) and fuel temp. (140℃) ➔ good atomization
- Sophisticated electronic control of injection ➔ can be adapted for 2 tanks system



Advantages:

Low NOx and particulate at low load (HCCI mode with diesel fuel)

Low NOx and particulate at high load (conventional mode with vegetable oils)


Thank you for your attention !
Muito obrigado !
Merci de votre attention !